

# Earth's oblateness changes from GPS, GLONASS, and SLR data

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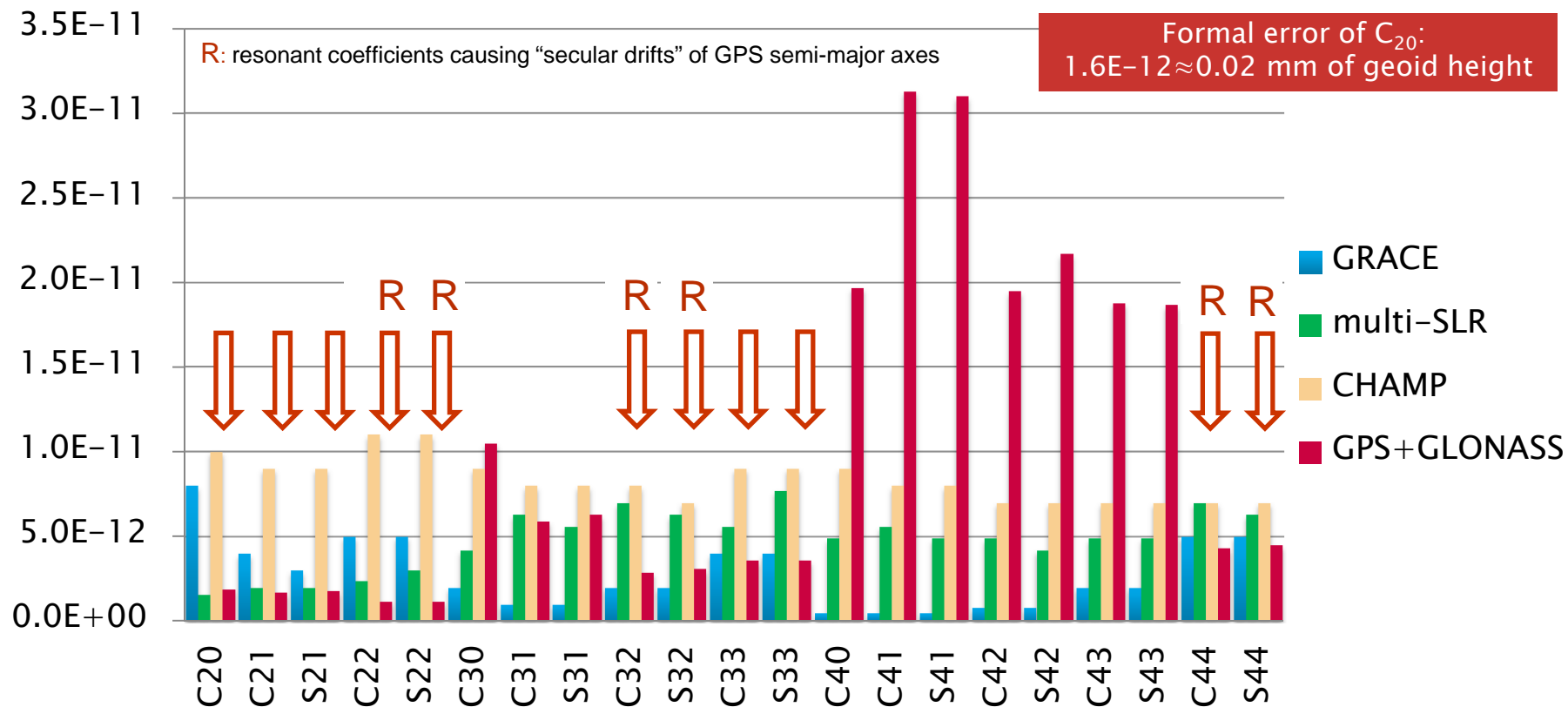
## Impact on Earth Rotation Parameters (ERPs)

- Pole coordinates
- Length-of-day

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# Sensitivity of GNSS solutions to low-degree gravity coeff.

## Mean a posteriori errors – monthly solutions



**GPS** satellites are very sensitive to gravity field coefficients of **degree 2**. For coefficients above degree 3, GNSS are typically very sensitive only to **resonant gravity field coefficients**.

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# GNSS solutions

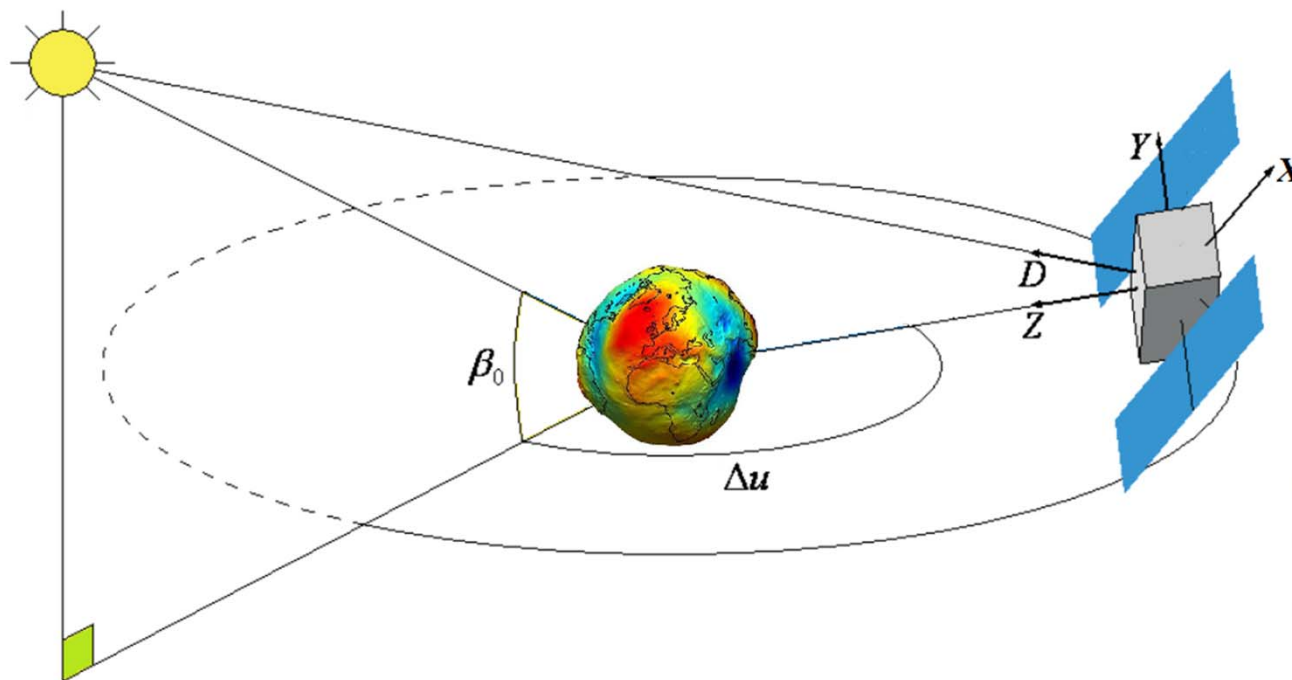
# List of estimated parameters & solution set-up

Estimated parameters		GNSS solutions
		up to 32 GPS and 24 GLONASS satellites
Orbits	Osculating elements	$a, e, i, \Omega, \omega, u_0$ (1 set per 3 days)
	Dynamical parameters	$D_0, Y_0, X_0, X_S, X_C$ – unconstrained $D_S, D_C, Y_S, Y_C$ – constrained at $10^{-12}$ (1 set per 3 days)
	Pseudo-stochastic pulses	$R, S, W$ (constrained, estimated every 12 <sup>h</sup> )
Earth rotation parameters		$X_P, Y_P, UT1-UTC$ (Piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 7 days
Earth gravity field		Estimated up to d/o 4/4 (1 set per 7 days)
Station coordinates		1 set per 7 days
Other parameters		Troposphere ZD (2h), gradients (24h) and ZTD biases

We processed **10 years** of **GPS** and **GLONASS** data using the standard orbit modeling as from CODE with **two** major **exceptions**:

- **7-day solutions** are generated instead of the 3-day long-arc solutions as for the IGS.
- The Earth's **gravity field coefficients** up to **degree/order 4/4** and **geocenter** coordinates are simultaneously estimated along with other parameters.

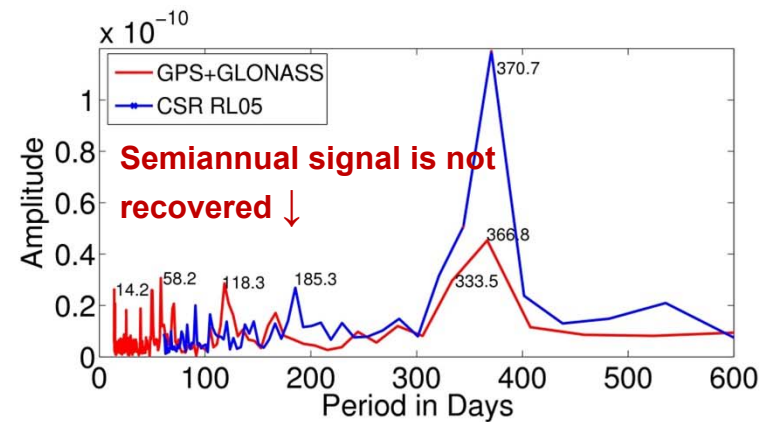
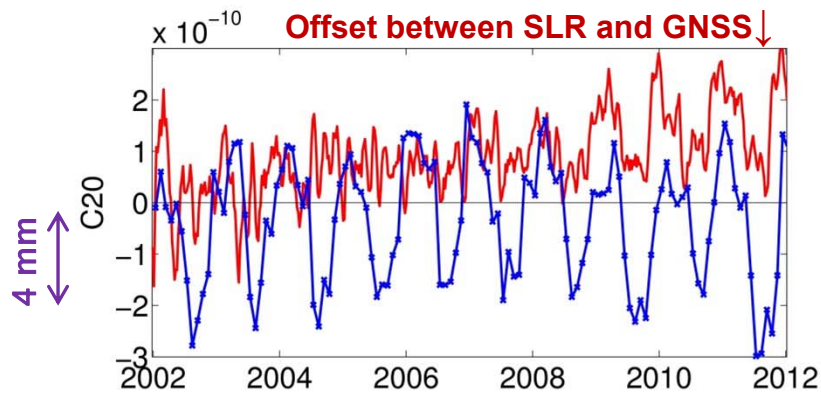
# GNSS orbit modeling



**GNSS** dynamic orbit parameters estimated in standard CODE solutions (reduced ECOM model):

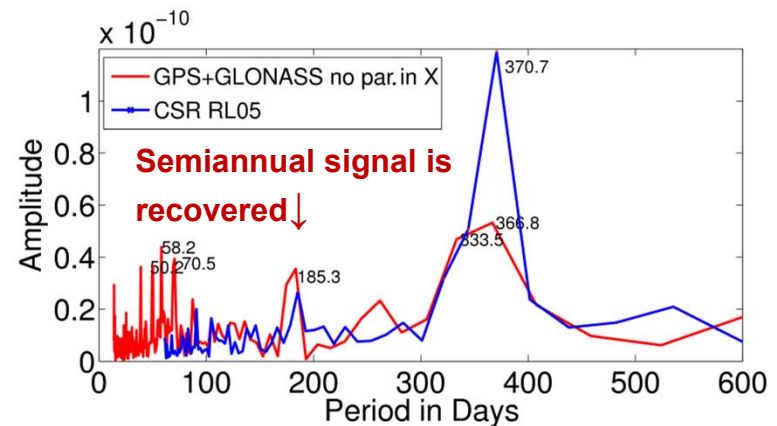
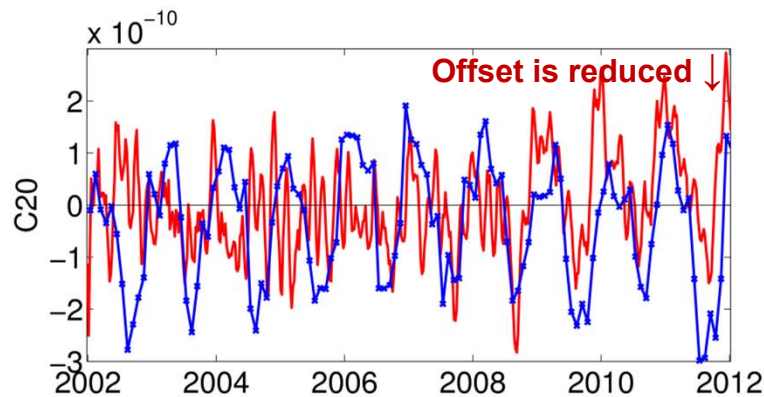
$$\begin{pmatrix} D \\ Y \\ X \end{pmatrix} = \begin{pmatrix} D_0 \\ Y_0 \\ X_0 + X_S \sin u + X_C \cos u \end{pmatrix}$$

# $C_{20}$ from GPS+GLONASS



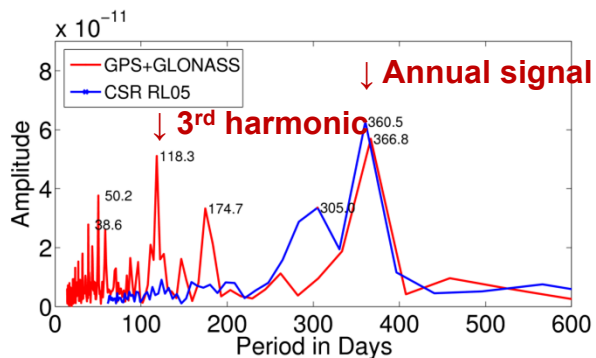
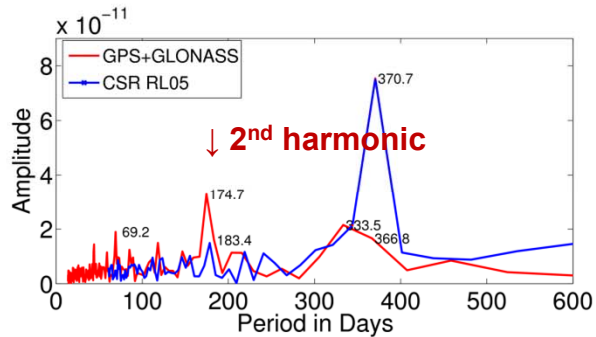
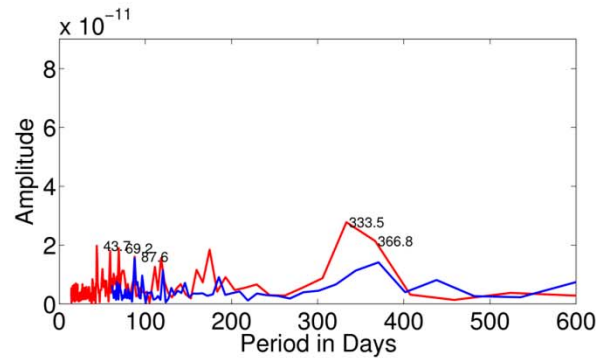
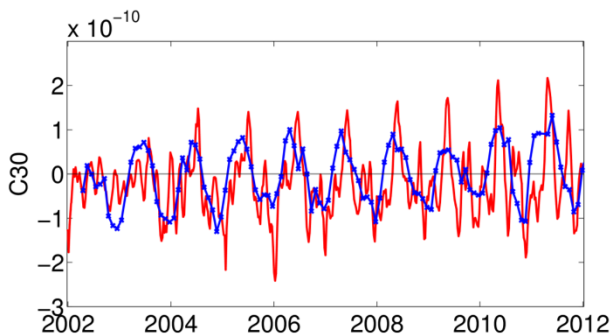
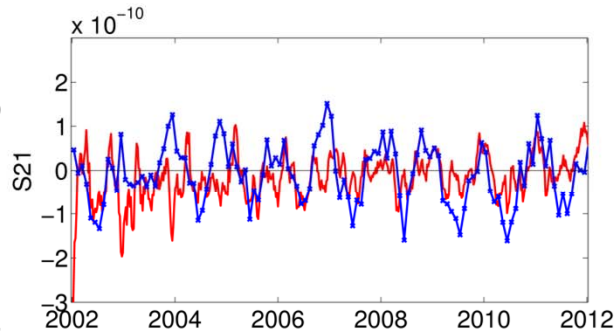
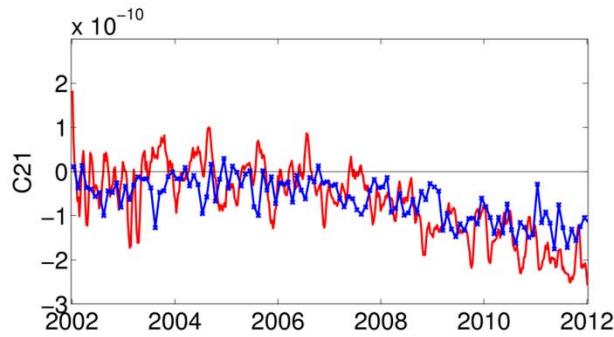
**GNSS dynamic orbit parameters :  $D_0, Y_0, X_0, X_s, X_c$**

**Orbit parameters in the X direction are correlated with  $C_{20}$**



**GNSS dynamic orbit parameters :  $D_0, Y_0, \cancel{X_0}, \cancel{X_s}, \cancel{X_c}$**

# $C_{21}$ , $S_{21}$ , $C_{30}$ from GPS+GLONASS



GNSS-derived gravity field parameters agree quite well with the CSR RL05 results (median difference of  $8.2 \cdot 10^{-11}$ ), but:

- GNSS-derived parameters show both: the **seasonal signals** as well as **draconitic periods**,
- $C_{20}$  is **correlated** with orbit parameters in the **X** direction.

Gravity coefficients benefit from the contribution of **GLONASS** (after **2008**, when the station coverage improves).



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# SLR solutions

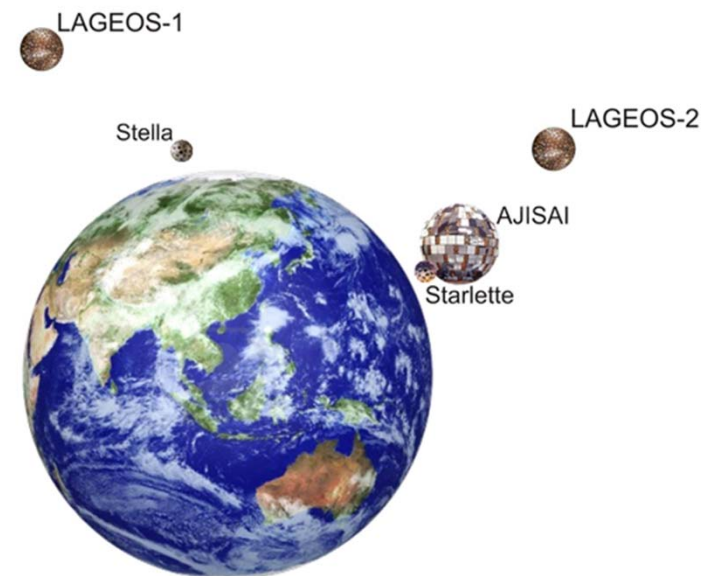
# List of estimated parameters & solution set-up

Estimated parameters		SLR solutions
Orbits	Osculating elements	LAGEOS-1/2, Starlette, Stella, AJISAI  $a, e, i, \Omega, \omega, u_0$ (1 set per 7 days)
	Dynamical parameters	LAGEOS-1/2 : $S_0, S_S, S_C$ (1 set per 7 days) Sta/Ste/AJI : $C_D, S_C, S_S, W_C, W_S$ (1 set per day)
	Pseudo-stochastic pulses	LAGEOS-1/2 : no pulses Sta/Ste/AJI : once-per-revolution in along-track only
	Earth rotation parameters	$X_P, Y_P, UT1-UTC$ (Piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 7 days
Earth gravity field		Estimated up to d/o 4/4 (1 set per 7 days)
Station coordinates		1 set per 7 days
Other parameters		Range biases for selected SLR stations

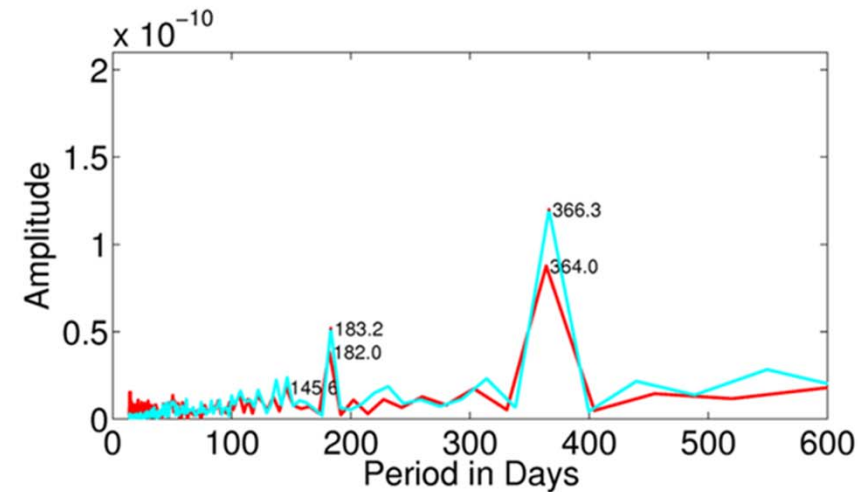
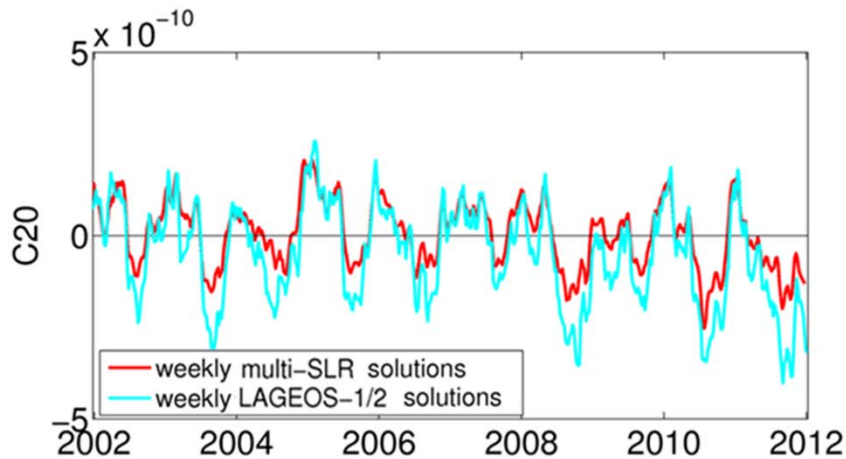
Once-per-revolution empirical parameters in out-of-plane are not estimated for LAGEOS, because they are directly correlated with  $C_{20}$ .

We processed **10 years** of SLR data to 5 geodetic satellites: **LAGEOS-1 / 2, Starlette, Stella, and AJISAI.**

Orbit modeling of low orbiting satellites (LEO) comprises more estimated parameters due to their higher sensitivity to non-gravitational perturbations (**atmospheric drag, albedo, direct radiation pressure**).



# $C_{20}$ from LAGEOS-only and multi-SLR

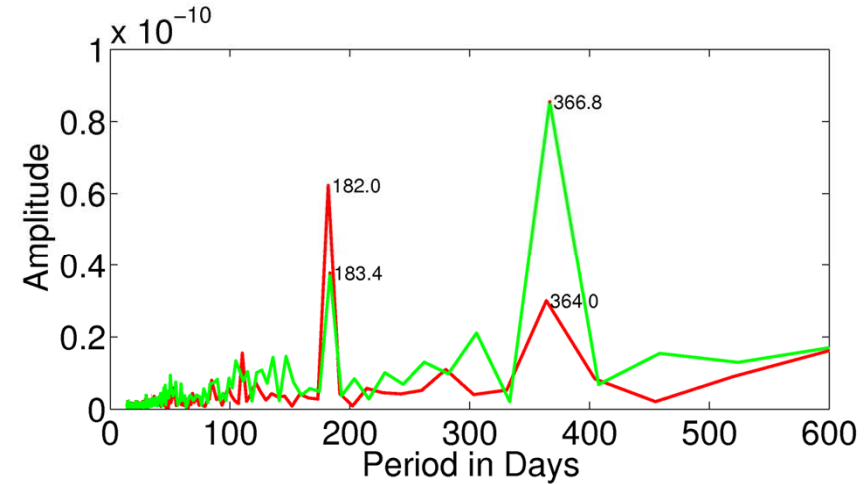
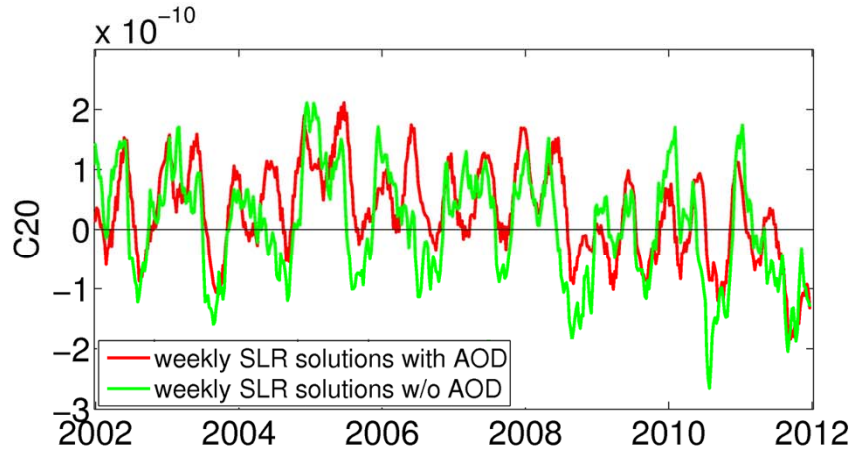


Variations of  $C_{20}$  from the **LAGEOS-only** solution are slightly **overestimated** due to correlations with other estimated parameters, e.g.:

- other **gravity field coefficients** (e.g.,  $C_{40}$ ),
- **Length-of-day**,
- Orbit parameters (e.g., ascending **node**),
- **Empirical orbit parameters** ( $S_0$ ,  $S_C$ ,  $S_S$ ).

The **multi-SLR solution** with five high and low orbiting SLR satellites is thus more robust.

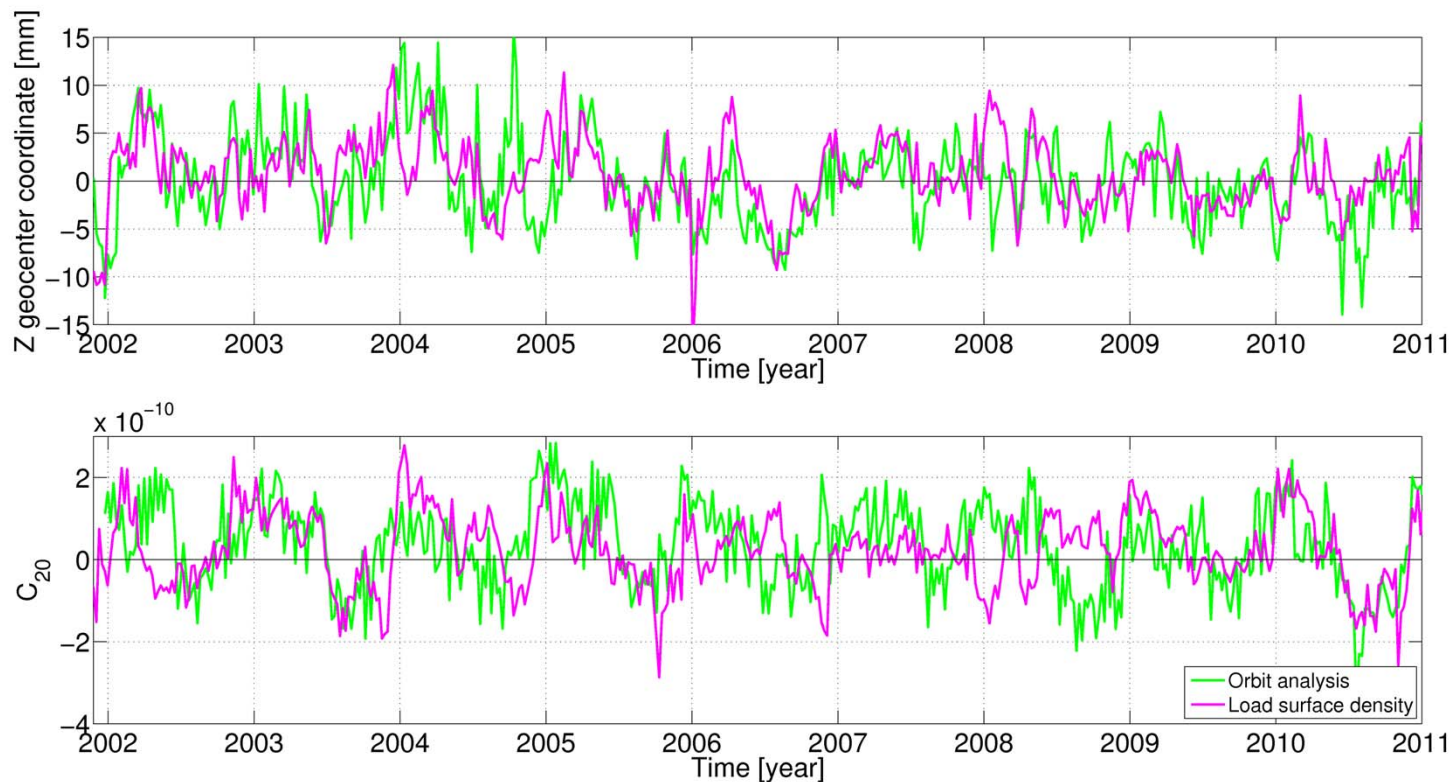
# $C_{20}$ from multi-SLR with and without AOD



When applying the time variable atmosphere and ocean gravity de-aliasing products (AOD), the estimated signal is changed, the **annual signal is decreased**, whereas the **semiannual signal is increased** w.r.t. the solution without AOD.

A full consistency between products must be kept when comparing different gravity field solutions (e.g., GRACE and SLR).

# $C_{20}$ from surface load

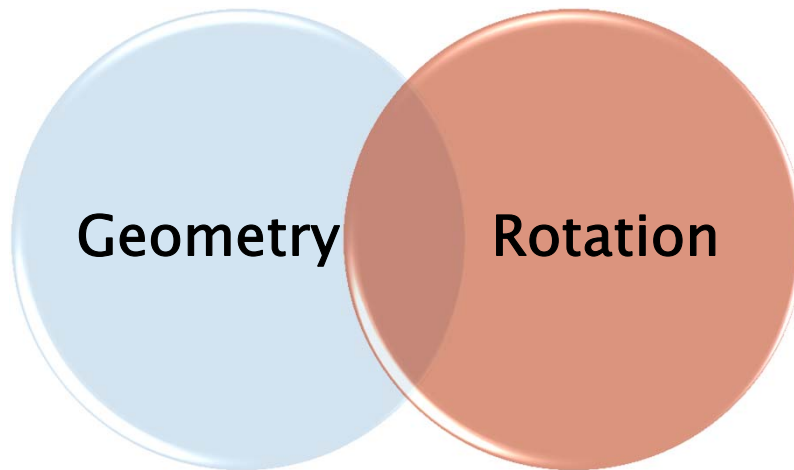


Variations of  $C_{20}$  can alternatively be recovered from **surface load density** variations, but this method is limited due to the **inhomogeneous distribution of SLR stations**. The correlation coefficients between “classical”  $C_{20}$  determination and  $C_{20}$  from station load displacements is **0.26** (and 0.53 for the Z geocenter coordinate).

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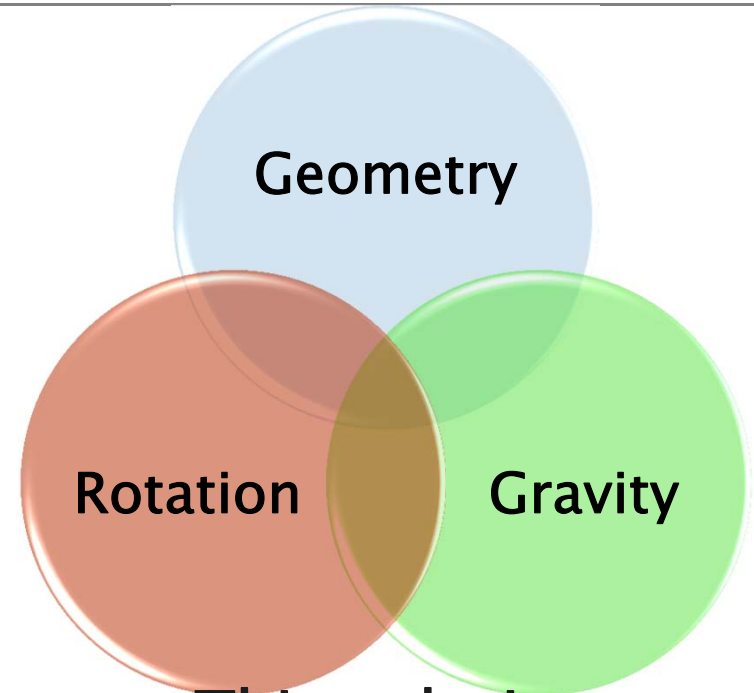
# Earth Rotation Parameters

# Three pillars of satellite geodesy



**Current status:**

IGS/ILRS provide products related to **Geometry** and **Rotation**, but **not yet** to temporal variations in the Earth's **Gravity** field.



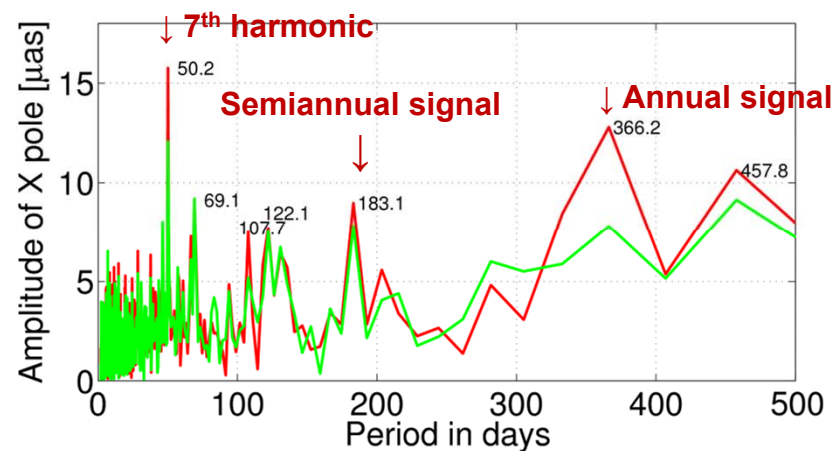
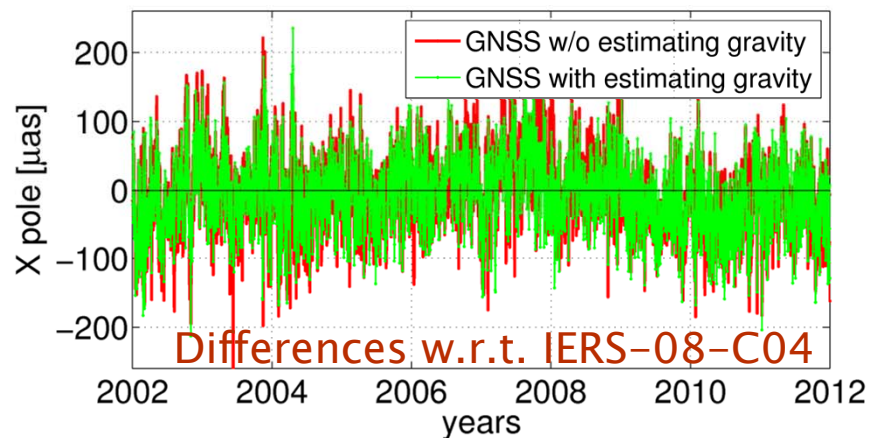
**This solution:**

Parameters related to **all three pillars** are simultaneously estimated, because they are strongly **dependent on each other**.

**How much affected are the GNSS/SLR-derived parameters by neglecting the temporal gravity field variations?**



# GNSS solutions – polar motion



For the **X pole coordinate**:

- the amplitude of the 7<sup>th</sup> harmonic is reduced from **15.9** to **12.2**  $\mu\text{s}$ ,
- the amplitude of the annual signal is reduced from **12.8** to **6.9**  $\mu\text{s}$ ,
- the mean offset w.r.t. IERS-08-C04 is reduced from **-10.5** to **-9.9**  $\mu\text{s}$ ,

for the solutions **without** and **with estimating gravity field** parameters, respectively.

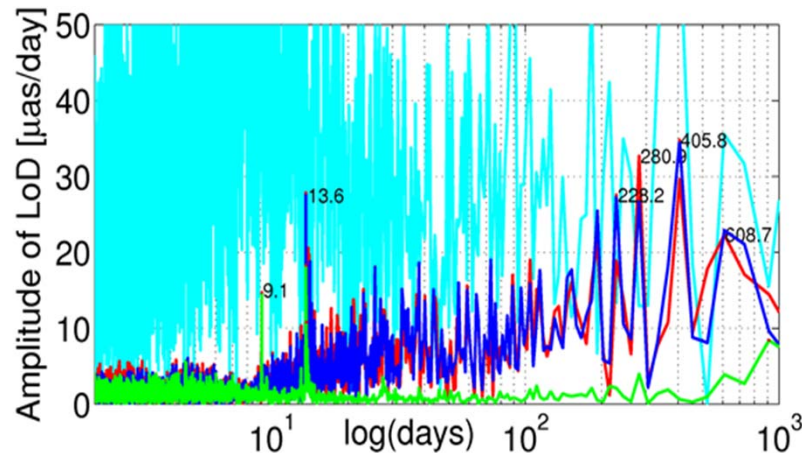
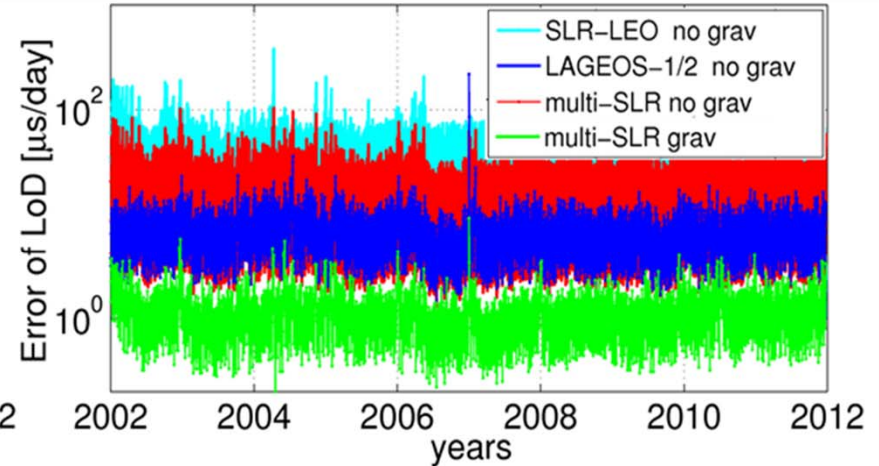
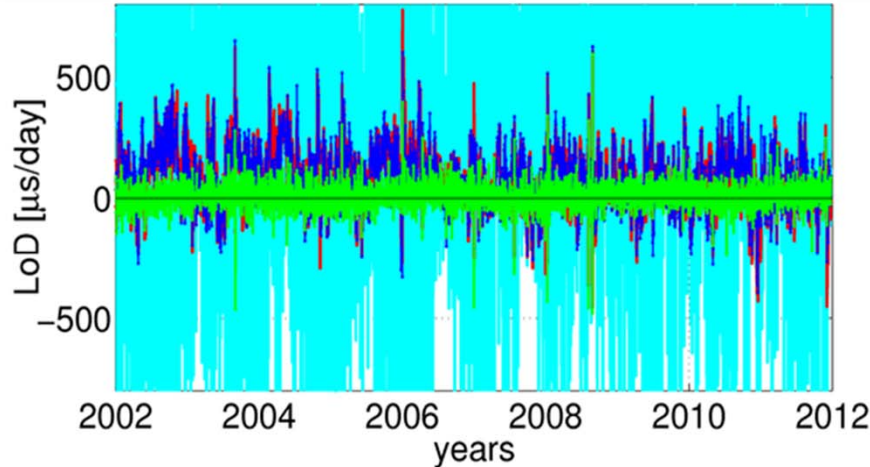
**A priori static gravity field is insufficient for current high-accurate GNSS products.**

**Temporal variations in gravity field should be considered.**



# SLR solution with and without estimating gravity field

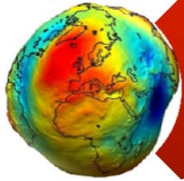
LoD w.r.t. IERS-08-C04



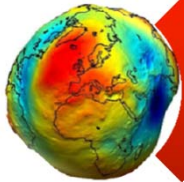
For **LoD**, the simultaneous estimation of the **gravity field parameters**:

- 1. reduces the **offset of LoD** estimates,
- 2. substantially reduces the **a posteriori error of estimated LoD**. The mean a posteriori error of LoD is **1.3**, **16.9**, **7.1**, and **44.6**  $\mu\text{s/day}$  in the **multi-SLR solution with gravity**, multi-SLR solution without gravity, LAGEOS-1/2 solution without gravity, and SLR-LEO solution without gravity field parameters, respectively.
- 2. reduces peaks in the spectral analysis, which correspond, e.g., to orbit modeling deficiencies (peaks of 222 days, i.e., draconitic year of LAGEOS-2, 280 days, i.e., eclipsing period of LAGEOS-1),

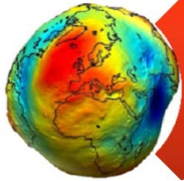
# Summary



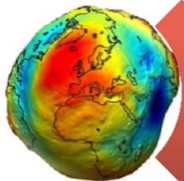
The GNSS satellites are sufficiently sensitive to low-degree gravity field parameters (including  $C_{20}$ ), to recover the temporal gravity field variations.



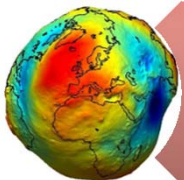
The empirical orbit parameters in the X direction are correlated with  $C_{20}$ , therefore the X-parameters partly absorb the  $C_{20}$  variations. However, not all the gravity variations are absorbed by empirical parameters.



Low orbiting SLR satellites improve the SLR solutions by reducing the correlations between estimated parameters. Mutli-SLR solutions with high and low orbiting SLR satellites is preferable as compared to LAGEOS-only.



The simultaneous estimation of gravity field parameters along with ERPs, station coordinates, and other parameters is feasible and it is beneficial, e.g., for estimated pole coordinates and length-of-day.



Temporal gravity field variations should be taken into account in both, the SLR and GNSS solutions.



# Thank you for your attention

The 40th COSPAR Scientific Assembly 2014

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